Intelligent Archive Visionary Use Case: Advanced Weather Forecast Scenario

July, 2003

Robert Harberts, L. Roelofs
Global Science & Technology, GST
Greenbelt, MD
Harberts@gst.com

H. K. Ramapriyan, C. Lynnes, G. McConaughy, K. McDonald, S. Kempler
NASA/GSFC
Greenbelt, MD

ABSTRACT

Because the volumes of data NASA expects to acquire from future missions and continue to accumulate over time will increase markedly, advances are needed in concepts and tools to enable intelligent data management. One such concept, the "intelligent archive" (IA), is actively being developed by a NASA study team to address various challenges associated with abundant data output from future observation missions and their use by scientific knowledge enterprises. A key goal is to get the most societal value from these data. The IA concept is envisioned to play a critical role in achieving this goal.

The study team has adopted an approach involving use case scenarios to aid in its exploration of challenges, issues, and requirements for developing the IA concept. By referencing visionary use cases for precision agriculture and advanced weather forecasting skill for example, IA concepts could be "exercised". In other words imaginative use case scenarios help the team better understand what capabilities would be required to manage and utilize massive data resources in dynamic distributed system environments projected for the 2015-2030 timeframe.

This white paper first introduces the IA concept and the use case approach to exploring concepts relevant to developing the intelligent archive concept. The main sections of the paper present a use case scenario based on advanced weather forecasting skill enabled by a weather forecast system visionary architecture. We then describe a futuristic scenario to illustrate examples of advanced system capabilities with implications for underlying functional supporting services and cyber infrastructure. A quantitative analysis of projected data volumes required to support the envisioned weather forecasting skill is assessed to identify challenges relevant to an IA. The paper concludes with an examination of challenges and requirements posed by this use case that can be addressed by intelligent systems research and envisioned IA capabilities to exploit that research.

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INTRODUCTION

Studies that look deeply into the next generation of data archiving systems are underway to address the challenge of getting the most societal benefit from large data volumes NASA expects to accumulate in the future. One such study sponsored by NASA Ames CICT explores the concept of an "Intelligent Archive" (IA) and its role within an end-to-end context. This context embraces a chain of systems extending from those involved in data acquisition to those that derive information and knowledge from these data for use by various societal enterprises. Implications of petabyte-era data volumes on systems and infrastructures supporting science-based applications stimulated research into new concepts for intelligent archives in the years 2015-2025.

Beyond the obvious dependencies on improvements in hardware technologies to meet requirements for storing and supporting efficient access to future distributed data volumes, advances are needed in concepts and tools to enable intelligent data management and utilization. While the growth rate and quantity of data increases rapidly, new challenges are posed to basic data management and utilization.

To address these challenges while developing a conceptual architecture for future archives we used an approach based on visionary scenarios describing data usage in applications combined with projections of advances in relevant technologies. In this manner an abstracted architecture could be defined without regard to physical implementation. Architectures for an IA could be considered from the point of view of the functions that need to exist in support of various usage scenarios. This approach is useful because the functions of an intelligent archive are more stable than the physical architectures and technologies used to implement them. By 'discovering' and abstracting required components and processes from scenarios into functional elements, we were able to explore application strategies of technologies and system resources for future intelligent archives.

An outgrowth of this approach is the concept for future capabilities and characteristics of an archive. An IA is differentiated from contemporary archives because the scope of meaning for the term 'archive' is extended from a simple repository of data to one that supports and facilitates derivation of information and knowledge. For example, stored items managed by an IA are extended to include [1]:

- Data, information, and knowledge
- Software needed to manage holdings
- Interfaces to algorithms and physical resources to support acquisition of data and their transformation into information and knowledge, storing the protocols to interact with other facilities

Thus, an IA is conceptualized within the context of a knowledge building system. With the application of intelligent algorithms and intelligent system components, an IA has greater ability to operate more autonomously than conventional archives. Additionally, an IA is envisioned to provide improved quality of responsive services to users (as an intelligent assistant) with less operator intervention. By embodying new capabilities an IA can be distinguished from archives of today with regard to its ability for [1]:

- Storing and managing full representations of data, information, and knowledge

- Building intelligence about transformations on data, information, knowledge, and accompanying services involved in a scientific enterprise
- Performing self-analysis to enrich metadata that adds value to the archive's holdings
- Performing change detection to develop trending information
- Interacting as a cooperative node in a "web" of other systems to perform knowledge building (where knowledge building involves the transformations from data to information to knowledge) instead of just data pipelining
- Being aware of other nodes in the knowledge building system (participating in open systems interfaces and protocols for virtualization, and collaborative interoperability)

As these IA functional capabilities become part of a knowledge building system many benefits for science applications can be imparted. This is inevitable due in large part to dynamic interdependencies that exist between science enterprise applications and IA services. Positive implications for other aspects of the knowledge building system that interact with an IA can similarly be expected. By broadly exploring the interactions missions, data and service providers, science applications, and science teams could have with various advanced IA capabilities a clearer understanding of these benefits and possibilities emerge. We adopted a use case scenario approach to explore the nature of some of these possibilities, implications, and benefits.

USING SCENARIOS TO ILLUSTRATE AND CLARIFY IA CONCEPTS

Imaginative use case scenarios provide a way to study limitations of existing solutions and the nature of challenges, issues, and probable opportunities for innovation. Scenarios of envisioned ways to use intelligent archive resources help identify candidate requirements for services and capabilities that can then be mapped to existing and future technology applications. Consequently, forward looking, tangible and imaginative scenarios lead to a flexible, more comprehensive architecture for future intelligent system applications.

Our approach was to start with processes for an existing use case (e.g. precision agriculture and advanced weather prediction) capabilities to explore ideas from which to extrapolate the possible and then develop more speculative and visionary scenarios. We studied use case scenarios with regard to advanced data/information requirements and the challenge of assimilating progressively massive amounts of available data. Studying a conceptual application domain such as advanced weather forecasting contributes to an appreciation of both context-specific requirements and those for common or generalized features of an intelligent archive. The following sections present a conceptual use case study based on an advanced weather forecasting scenario.

ADVANCED WEATHER FORECASTING SKILL USE CASE

Earth science models provide the primary tool for weather forecasting. The basic concept involves applying a suite of equations (models) to measurements of heat, cloudiness, humidity, and other integral parameters to project how those factors change over time – thus forecasting the behavior of the atmosphere. Because weather forecasting science attempts to accurately simulate the real world, it must rely on observations, modeling, and theory. If science can get the weather models right with more detailed observations, then we could see nearly perfect three-day forecasts and even reliable ones beyond ten days [2.]

Models are made of complex computer code that divides the atmosphere, land, and oceans into hundreds of interacting grids. Until recently, the resolution of the grid boxes has been as large as 296 km on a side. This meant that many of the Earth's features that affect changes in weather were smaller than the boxes and had to be approximated. New models are now approaching 32 km on a side and can account for more of these details (but still not all of them). This refined resolution provides more precision in the model and hence, more accuracy in its predictive power. However, these improvements in resolution do not come without presenting another challenge.

There are trade offs between detail and time due to current computing limitations. As Dr. Geoff Jenkins of the United Kingdom's Hadley Center for Climate Prediction and Research notes, the four dimensional nature of the problem and the doubling of resolution requires a sixteen-fold increase in computing. He states that when they tested the Hadley Center's 32 km resolution model, it "completely clogged" one of their supercomputers [3.].

To address such an issue, the Japanese have linked 5,120 high-speed processors to yield 40 trillion calculations per second computing performance. (This compared to the current contender with 1000 slower processors performing at about one hundredth the speed [3.].)

Yet being able to process more data quickly does not guarantee accurate weather forecasting. Weather forecasting skill is a process involving observation, modeling, and theory. Additional issues such as determining the correct initial conditions for starting models need to be addressed when attempting to minimize errors and prevent models from straying into uselessness. Next generation systems envisioned to support and improve this process are described in the following sections of the advanced weather prediction scenario.

WEATHER FORECASTING SYSTEM

The context for a future weather forecasting skill scenario highlights interrelationships that exist among observations, science, information services, and information consumers. A significant part of the context includes conceptual elements of the ESTO Weather Prediction Technology Investment Study [4.]. This study identified science applications and technology required to enable skilled weather forecasts of ten to fourteen days by 2025. Overall actors in this context include weather science teams; weather observing systems (including remote sensing and in situ measurements i.e. buoys, balloons, radiosondes, ground-based instruments), data processing, modeling, dissemination, and archiving groups; weather prediction information services; and weather information consumers (see Figure 1).

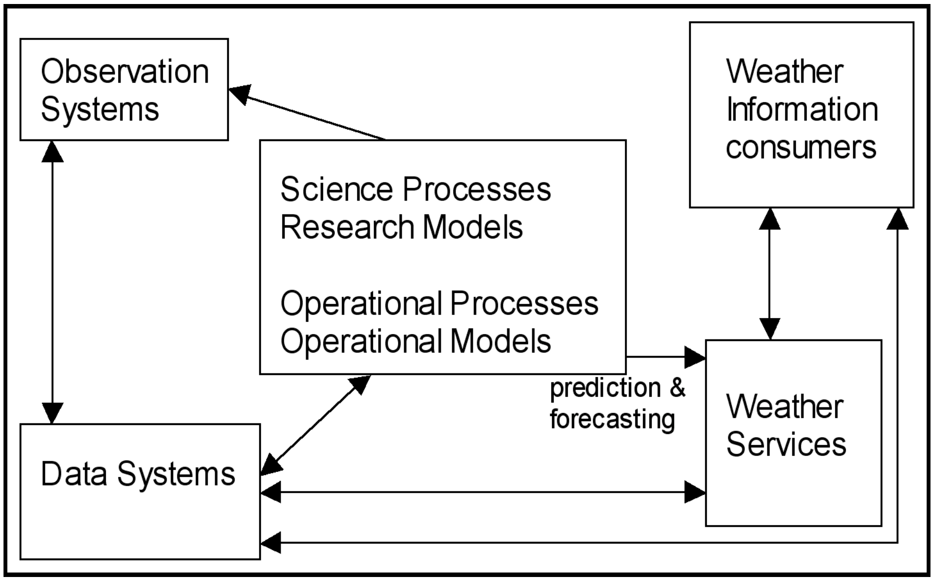

Figure 1: Systems Context

Context actors are engaged in an enterprise that strives to achieve accurate weather forecasts and provide consumers with improved weather information services. This is an iterative research process with practical applications, one in which science and traditional weather services are strongly interrelated. The overarching system in this context description is a composite of collaborating subsystems, each viewable as its own integrated enterprise (e.g. weather science and data systems, and weather information and consumer services.) The following sections focus attention on a future weather science enterprise.

FUTURE WEATHER SCIENCE CONCEPT AND REQUIREMENT DRIVERS

Atmospheric and climate sciences collect and assimilate data into research models. Building and improving models is an integral part of this knowledge enterprise. The end-to-end process for weather model building currently involves instrumentation for collecting observations, developing algorithms and forward models for assimilation, integrating data into operational products, and assessing impact of data on forecast models. Both the research and operational communities (e.g., National Centers for Environmental Prediction, National Weather Service, NOAA) rely on sophisticated weather modeling for progressively better government and public services. The next section explores science enterprise drivers.

WEATHER FORECASTING SCIENCE SKILL CONCEPT

Predicting or forecasting future weather conditions over a particular region requires accurate data and knowledge about atmospheric forces, physical parameters, and the interrelatedness of atmosphere to the whole Earth system. While such knowledge is incomplete, scientific processes and visionary methods for improving that knowledge promise more accurate forecasts of atmospheric behaviors. However, the accuracy of weather predictions tend to fade rapidly as a function of time due to a lack of precise initial conditions and the non-linear complexities of weather. The following futuristic advanced weather prediction concept provides insight into an approach that overcomes this challenge (to a point) while simultaneously increasing knowledge and evolving models capable of improved predictive accuracy.

EXAMPLE IMAGINED SCENARIO

In the mid-Atlantic region of North America, scientists are engaged in studying a developing weather condition. An opportunity emerges for gaining important insights into the particular weather system by testing a beta version of their 4-D model of the region. It also presents a chance to creatively exercise a national and international infrastructure of intelligent observational tools, services, and resources. The scientists elect to perform a set of scaled predictions for a eight hundred square kilometer region, zooming down progressively to a research farm on the Delmarva Peninsula. The research team plans to forecast weather conditions as precisely as possible for the next ten days.

Planning sessions are conducted with an interactive visualization interface equipped with collaborative and immersive human-machine technology. Team members have the option to meet virtually via their workstation or in one of the research center's hypermedia tele-immersive conference rooms. In the tele-immersive room, the scientists plan their research forecasts by summoning a vivid holographic 3-D projection of the Earth, pointing to the region of interest, zooming in, and accessing projections of scaled real-time weather conditions.

By accessing a console, one scientist views options for interactive displays. She cycles through several current satellite views of the region selected from a list and scans each view. Next she requests views of the latest graphics and values for temperature, pressure, humidity, and winds superimposed over the satellite image slightly above the defined region on the global reference projection. In order to assess the whole virtual picture of the weather condition, the team requests that the system detach the selected region from the reference globe and project it as a cube presenting a 3-D visualization of the weather conditions to an altitude of 25,000 meters. By rotating the cube the researchers inspect the sensor grid sensitivities over the region from every angle.

The team next decides to run one hour, one day, five day, and ten day forecasts of weather for this region using the current operational model, adding some custom–selected inputs from a sensor array pick-list. After a minute, the results are ready to be displayed in the same virtual region cubic space. The team studies each forecast display by a variety of interactive real-time commands (by voice, gesture, and keyboard). They explore the 4-D visualizations by varying the temporal resolution, zooming spatial areas/volumes to inspect details, requesting displays of simultaneous analysis result visualizations, and selecting predicted parameters for further comparative analysis. Some team members even perform dynamic what-if prediction scenarios comparing what the system generates with their own hypotheses.

With this experience the team then formulates a test of their beta version model using insights gained from the immersive collaborative session. Several on the team notice that higher resolution remote sensing values are needed in certain areas of the region to accurately predict future changes of the pending weather condition. This might accord with the deviation of the standard model from theoretical expectation after one day. Furthermore, there is team consensus that coupling their beta model with selected components of the standard model would elucidate new dependencies and parameters crucial to accurate predictions. Scientist-provided specifications for this new research configuration are then interpreted, translated, brokered, and automatically tasked by the system.

In the final episode of this scenario the team studies the emerging weather phenomenon through virtual projections of real-time information and various combinations of modeled predictions. For the modeling portion of the research, the team observes how the standard model adjusts its own forecasts as a function of near-real time automated comparison of actual versus predicted parameters. When the predicted parameters vary too much from the actual, new initial conditions are set. This continually keeps the predictive accuracy on track for the near term, but progressive adjustments of the model are required. The standard model in this scenario has intelligence applied so it monitors its own performance. With access to a knowledge base, the model may also pinpoint components to be modified either automatically or by human intervention.

In parallel with this modeling activity, the team custom-configures its beta version model. They include a system request that re-tasks the sensor web to gather highly detailed inputs for a critical area of the study region, to generate new forecasts. When first studied (in the tele-immersive conference room) team members recognized the standard sensor grid resolution was too low for their investigation. They decide to request finer resolution sampling from the sensor web. The sensor web schedules and promptly complies with the request, producing critical detailed data for the beta model to process.

Ten days after the start of the research event, the team was able to conclude from their findings that new knowledge was gained about the rare weather condition. Furthermore, comparisons of performance and outcomes between the beta and standard models identified strong points in the beta model responsible for improving the accuracy of overall forecasts. Validation of these findings led to the promotion of specific beta version components and two external model linkages to the standard model, adding a new phenomenon to the knowledge base with additional predictive power. The team also embarked on a new research direction that involved fitting a microclimate model of a farm into the regional model.

UNDERLYING VISION SYSTEM DESCRIPTION

Making possible the above visionary scenario obviously involves developing new observation sensor systems with innovative science and technology applications. Improvements to existing capabilities combined with evolving infrastructures and innovative research technologies can enable skilled weather forecasts of ten to fourteen days by 2025 (current forecast predictive skill is five to seven days) [4.]. Skilled forecasting goals such as this require quality, mixed-resolution observations and data acquisition systems; very rapid processing of observations; complex data assimilation strategies; predictive modeling strategies and algorithms; and powerful archiving, distribution, and interactive visualization technology infrastructures. Key aspects of a visionary system for advanced weather model building and operation would include:

- Flexible, intelligent global observing system (sensor web)
- Modeling/data assimilation systems
- Global mesoscale atmospheric prediction model

The observing system provides comprehensive observations and measurements in real time. It must be flexible to provide special observations on demand. And, optimally, the observation system combines all sources of sensor assets for surface, atmospheric, and space–based data. The envisioned sensor web will be reconfigurable and tasked in response to evolving model requirements or events of interest. The modeling and data assimilation system couples terrestrial and space observations to a continuously running mesoscale model. In this manner, the global mesoscale model's sophisticated parameterization can be updated quickly and regularly with actual observational inputs. This kind of periodic infusion of actual observational inputs into the model overcomes model "drift".

While the theoretical upper limit of weather forecasts is two weeks, the operational advanced weather system pushes the limit on getting essential initial conditions (actual state) of the atmosphere at any model starting time. A two-way interactive global observing and modeling / data assimilation system can autonomously tailor observing strategies based on knowledge of current and future states of the atmosphere. These types of interactions can confirm, predict, and validate model parameterizations or make measurements in specific locations to improve models and forecasts. The system can also anticipate support of reconfigurable prediction models based on autonomously obtained observation inputs. Overall complexities of coordinating and commanding interaction among the interdependent parts of the overall system will require system-wide embedded intelligence, ensuring seamless consistent operational orchestration and control.

QUANTITATIVE DATA ASSESSMENT

In addition to observation, assimilation, and modeling systems, there remain challenging data requirements to achieve skilled fourteen-day forecasts. The optimized combination of observing system and model data needs to be capable of providing [4.]:

- Structure information in the free atmosphere every three hours, every 25km globally (horizontal resolutions from 25km to 1km depending on measurement/model requirement), and vertically from the surface to 80km altitude (at 250m vertical resolution)
- Global 3D distribution of clouds (height, depth, water/ice, aerosols)
- Global 3D distributions of suspended precipitation (rates @ 2mm/hour)
- Land and sea surface temperature, land surface moisture, albedo, vegetation type
- Planetary boundary layer depth

Space-based, airborne, and terrestrial sensors will produce weather-related data with varied resolutions, rates, bands, parameters, and volumes. Models and analytical tools will also generate data (though the bulk will come from remote and in situ sources). An assessment of expected optimized global data volumes covering required parameters, temporal/horizontal/vertical resolutions, and vertical measurement layers yields an estimate of about 20GB/day by 2025 (see Table 1). Advanced weather forecasting, as illustrated in this scenario, represents a data and processing-intensive knowledge enterprise. Clearly many functional capabilities and performance levels have yet to be developed to implement such a system. Visionary science and the value of the knowledge it promises will continue to drive the evolution of technology applications that can help achieve high skill forecasting goals.

Earth Surface Area	509805891		1mb altitude	50		Bytes/Obs	4	
Parameter	**Temporal Res (hrs)**	**Horizontal Res (km)**	**Vertical Res (km)**	**Vertical Measurements**	**Param Mult**	**Compression**	**Millions of obs / day**	**Daily Volume (GB)**
3D Temperature	3	25	0.25	200	4	2	5220	10
3D Humidity	3	25	0.25	200	4	2	5220	10
3d Pressure	3	25	0.25	200	4	2	5220	10
3d Wind	3	25	0.25	200	12	2	15661	29
3d Precipitation	1	1	0.25	200	4	6	9788273	6077
3d Cloud height	1	1	0.25	4	4	2	195765	365
3d Cloud depth	1	1	0.25	4	4	2	195765	365
3d H2O Content	1	1	0.25	200	4	3	9788273	12155
Land surface moisture	1	1		1	4	6	48941	30
Land surface skin temperature	1	1		1	4	6	48941	30
Planetary Boundary Layer Height	1	1	0.025	1	4	4	48941	46
Snow/Ice	3	25		1	8	6	52	0
Sea Surface Skin Temperature	6	25		1	4	3	13	0
Aerosols	6	1		1	10	2	20392	38
Albedo	6	1		1	4	2	8157	15
Vegetation State	168	1		1	100	2	7283	14
Surface Roughness	336	1		1	4	2	146	0
								19193

Table 1: Initial Advanced Weather Forecasting Data Volume Assessment By 2025

DISCUSSION

The assessment results were based on the temporal, horizontal and vertical resolutions requirement suggested by the ESTO Weather Prediction Technology Investment Study's "Measurement Needs." The "soft" part of those numbers is likely to be the number of parameters. They were derived from scientists on the ESTO Weather study team. Refinement of these numbers will come from the larger weather research science community especially for precipitation and water content.

The weather prediction study group's data volume requirements assessment is still in a very early stage. Their tradeoff will be how much aggregation can be done onboard versus on the ground. While the bulk of processing will probably be ground-based the goal for producing a 14-day global forecast will be one forecast every 12-15 hours. For a quarter-minute time-step, fourteen-day global forecast at 1km horizontal resolution/50km vertical, with one hundred vertical levels, it would take an estimated 220 years to process at current computational speeds (assumed to be ninety-eight minutes for a seven and a half minute time-step forecast with 80km horizontal resolution/43km vertical limit, and forty-two vertical levels). This is between one and three orders of magnitude short of where computers will probably be in 2025 (extrapolating Moores' Law to 2025 only gives an improvement of computing power by a factor of 100,000 compared to the required 1,000,000).

One approach under discussion is to distribute some forecast processing functions up front onto the many satellites that will be needed. This might save an order of magnitude of processing on the ground, but it will mean more processing onboard spacecraft which would be more expensive. This is a little different than the usual on-board processing just to save communication bandwidth, although that is a piece of the equation [5.].

IMPLICATIONS FOR INTELLIGENT SYSTEMS AND INTELLIGENT ARCHIVES

Independent or weakly interoperable data collection, processing, and archiving systems are not conducive to achieving advanced weather forecasting goals. As the scenario indicates, the components of the overall system collaborate in a strongly interoperable and often bi-directional flow. For example, the analysis/assimilation/modeling component can receive data as well as interact with sensors on a dynamic basis. Furthermore, there is tight coupling between actual and predicted parameter values for model operation and model development. A significant challenge for this vision system is being able to rapidly transform acquired data into usable form in near real-time. How and where the computation/processing burden is performed throughout the envisioned distributed system environment remains a requirement for the architecture. Strongly interoperable distributed systems will correspondingly require significant intelligence to orchestrate and manage efficient robust operations.

Several opportunities for intelligent system applications can be identified for architectural segments of the weather forecasting system. Some examples will illustrate this assertion. For instance, the observing system segment requires intelligence for:

- Observation management (overall arrays and individual members)
- Scheduling, commanding, onboard operational autonomy management
- Distributed processing coordination
- Automated calibration and quality control, communications integrity
- Translating dynamic observation requests into optimal and timely results
- Implementing flexibility within and across platforms
- Tailoring observing strategies based on knowledge of current states
- Detecting, recognizing, and capturing specific events, states, and phenomena
- Registering and tagging observation data with appropriate information compliant with standards for product development and use by other archives, systems, disciplines, and campaigns
- Adapting to new configurations autonomously or from human command.

Opportunities for applying intelligent systems to the modeling/data assimilation system segment may include:

- Data ingest management
- Data assimilation
- Brokering observational data requests and observation targeting decisions
- Interpreting input data for any required recalibration, transformation, re-projections, conversions
- Facilitating model coupling

- Modeling data grooming
- Data mining/data understanding, automated analysis
- Determining where data collection is needed
- Automatically detecting gaps or quality issues
- Management of model results for interoperability
- Creation of information and knowledge products

In addition to system-to-system and within-segment processing opportunities for machine intelligence, intelligent applications are required for facilitating human-in-the-loop interactions. These areas include monitoring, control, recovery, tuning, operation, and modification functions. Other human-facilitated areas pertain to the creation of user-specified and standard weather products based on data and model results. Validation and quality assessment of these weather products also involve human judgments that need to be facilitated and enhanced with intelligent automation to improve accuracy.

Data management issues underlie the end-to-end system. Because of the real-time and near real-time characteristics of the visionary weather forecasting system, a heavy premium is placed on dynamic data management. This is reinforced by the distributed data processing that will also occur in various parts of the overall system (e.g., at the sensor source, in a data processing facility, at an archive, a modeling center, a science analysis team). Therefore in some operational cases, observational data may be used by advanced weather modeling facilities before they are archived.

On the other hand, sensor webs and data assimilation/modeling centers will generate huge volumes of data and information, necessitating new intelligent data management strategies to cope with the dynamic complexities associated with acquisition, processing, use, and persistence. For example, a weather prediction system will need to store the model's forecast for the entire Earth at a high 4D grid resolution for at least six days in the past of T= zero, and six days in the future. This stored model must be accessible to all sensors taking actual measurements of parameters that have been calculated everywhere the sensor web makes observations. Intelligent data management and access to these massive data stores on a dynamic basis indicates a critical need for an intelligent data archive solution.

TIE-IN TECHNOLOGIES AND OPPORTUNITIES

Making possible the above vision scenario obviously involves developing new observation sensor systems with innovative science and technology applications. Improvements to existing capabilities combined with evolving infrastructures and innovative research technologies can enable skilled weather forecasts of ten to fourteen days by 2025 (current forecast predictive skill is five to seven days) [4.].

Skilled forecasting goals such as this require quality, mixed-resolution observations and data acquisition systems; very rapid processing of observations; complex data assimilation strategies; predictive modeling strategies and algorithms; and powerful archiving, distribution, and interactive visualization technology infrastructures. Key aspects of a visionary system for advanced weather model building and operation would include:

- Flexible, intelligent global observing system (sensor web)

- Modeling/data assimilation systems
- Global mesoscale atmospheric prediction model
- High-speed computation, data, and communication cyber infrastructure

CONCLUSIONS

Advanced weather forecasting, as illustrated in this scenario, represents a data and processing-intensive knowledge enterprise. The future of skilled weather and climate forecasting science will rely on an advanced cooperative computing infrastructure coupled with widespread networks of sensors that produce very large volumes of data. Cyber infrastructures will comprise distributed system components (e.g., sensors, services, modeling, information & knowledge discovery tools) operating in a high-speed intelligence-based computing environment. This interconnected computing environment, in which IAs also operate, provides the collective processing, data management, data persistence, and data interchange services necessary to meet the near-real-time requirements for advanced weather prediction.

Visionary science goals exemplified in the use case for advanced weather forecasting skill help serve as requirement drivers for inspiring technology innovation and for creative applications of emerging and future information technologies. They also afford interesting research challenges for systems architects and developers to address with innovative technology applications. The challenge of how to support rapid access and transformation of data resources into weather modeling processes near real-time, for instance, defines a particular functional/performance challenge for IAs. Weather forecasting system reliance on IAs to participate in the overall orchestration of data resources, both as input and output from models, levies requirements that a future IA be robust as well as highly responsive.

Responsiveness of future systems predicated on strongly interoperable cooperative/collaborative functional elements (e.g. observing system, archive, science discovery tools) require significant intelligence to orchestrate and manage efficient robust operations. Intelligent systems promise to permit the kinds of complex decision processing necessary to achieve high responsiveness expected of interoperating systems. Similarly the IA will also need to operate intelligently with other distributed elements in the cyber infrastructure including associated enterprise applications. Developing intelligent interfaces and strategies for collaborative systems merit additional intelligent systems research. Beyond the specifics of an IA that supports a particular scientific enterprise (or use case for example) reside questions about multi-purpose and generalized IA capabilities. Questions about generalized versus customized intelligent archive services highlight areas for productive research to identify where best to develop and embed system intelligence.

REFERENCES

[1.] Ramapriyan, H. K., G. McConaughy, C. Lynnes, S. Kempler, K. McDonald, R. Harberts, L. Roelofs, and P. Baker, 2002, "Conceptual Study of Intelligent Archives of the Future", Report prepared for the Intelligent Data Understanding program, pp.4-8, http://daac.gsfc.nasa.gov/IDA_report_8_27_02_baseline.pdf.

[2.] Matthews, Robert, "Don't Blame the Butterfly," *New Scientist*, August 2001, pp. 25-27.

[3.] Revkin, Andew, "Climate Research: The Devil Is In the Details," *New York Times*, 3 July 2001.

[4.] Steiner, Mark, "ESTO Weather Prediction Technology Investment Study," NASA GSFC, October 5, 2001

[5.] Muller, Ron, personal communication, NASA, GSFC, 2002